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**Original Article**

# Relationships between single-leg jumping ability and isotonic strength of the trunk and lower limb

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**Abstract**:
This study investigated the characteristics of the single-leg countermovement jump (SCMJ) and single-leg rebound jump (SRJ), and examined their relationships with isotonic strength parameters of the trunk and lower limbs in healthy young adults. Eleven female university students, all with similar levels of physical activity, voluntarily participated in the study. Participants performed a series of SCMJ and SRJ trials, during which contact time and jump height were carefully recorded using high-precision measurement devices. Isotonic strength was assessed using a dynamometer to measure the peak concentric torque of the trunk extensors, hip extensors, hip abductors, knee extensors, and ankle plantar flexors. Correlations between the jump performance indices and the isotonic strength parameters were analyzed to identify key muscular contributors to single-leg jump performance. Analysis of peak concentric torque values revealed that hip abduction torque was lower than hip extension and knee extension torque but higher than ankle plantar flexion torque. The SCMJ jump height exhibited moderate to strong positive correlations with trunk extension torque, hip abduction torque, hip extension torque, ankle plantar flexion torque, and the total lower limb extension torque. In contrast, no significant correlations were found between SRJ jump height and the absolute peak torque values of any individual muscle group. However, a moderate positive correlation was observed between SRJ jump height and the proportion of hip extension torque relative to the total lower limb extension torque. These findings suggest that trunk and hip extensor strength play crucial roles in enhancing single-leg jumping performance, particularly in the SCMJ and SRJ.
**Key Words**: **Plyometrics, Countermovement jump, rebound jump, Stretch-Shortening Cycle, Cybex**

## Introduction

The countermovement jump (CMJ) is typically characterized as a jumping movement with a relatively long contact time, whereas the rebound jump (RJ) is classified as a ballistic jumping action with an extremely short contact time (Zushi et al., 1993). The CMJ is commonly regarded as a measure of vertical mechanical work performed against body mass, making it a simple yet effective method for assessing trunk and total lower limb extension torque (Kaneko et al., 1982). In contrast, RJ performance is often evaluated using the rebound jump index (RJ-index), calculated by dividing jump height by ground contact time (Zushi et al., 1993). An increase in the RJ-index can be achieved either by reducing ground contact time or increasing jump height. Thus, RJ serves as a comprehensive assessment of an individual's ability to generate greater trunk and lower limb muscle strength to achieve higher jump performance while minimizing contact time (Shide & Shinkaiya, 1996; Yoshida et al., 2018).

Several studies have investigated the relationship between isometric or isokinetic knee and ankle joint function and jump height in CMJs and drop jumps (DJs) from various platform heights using an isokinetic dynamometer—a widely used device for muscle function analysis (Destaso et al., 1997; Tanaka et al., 2006; Shimizu et al., 2024). For instance, Destaso et al. (1997) examined the association between DJ height and joint torque exerted by the knee extensors and ankle plantar flexors during concentric and eccentric contractions at an angular velocity of 120°/s. Their findings indicated a significant positive correlation between DJ height and peak knee extension torque. Similarly, Tanaka et al. (2006) investigated the effects of an eight-week training program on CMJ performance in 21 female university students, dividing them into three groups: an ankle dorsiflexion training group, a knee extension-flexion training group, and a non-training control group. The results demonstrated a significant positive correlation between CMJ height and peak ankle plantar flexion torque ($r = 0.528$, $p < 0.05$), with a significant improvement in CMJ height observed only in the ankle dorsiflexion training

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group. However, despite these findings, research exploring the relationship between jump performance and trunk and hip muscle strength remains limited.

Moreover, the aforementioned studies predominantly focused on two-legged jumps. In contrast, single-leg jumping poses greater instability due to a narrower base of support compared to bilateral takeoffs. This increased instability likely necessitates more refined body control and muscle activation, while the additional body mass supported by a single limb may further challenge postural balance between the left and right sides. Additionally, most prior research has emphasized dynamic force generation characteristics during jumping movements, such as joint torque production and mechanical work exerted during the jump itself (Takamatsu et al., 1989; Ae et al., 1994; Zushi & Takamatsu, 1996). However, athletes with superior jumping ability may also exhibit inherently greater isotonic strength, such as peak joint torque output measured through strength assessments, either in the trunk or the lower limbs.

Therefore, the purpose of this study was to clarify the characteristics of the single-leg countermovement jump (SCMJ) and single-leg rebound jump (SRJ) and to examine their relationship with isotonic strength parameters of the trunk and lower limbs. We hypothesized that individuals with superior total lower limb extension torque, particularly hip extension torque with larger muscle groups, would achieve higher jump heights in SCMJ. Furthermore, given that upper body postural control plays a crucial role in achieving greater jump heights within a shorter ground contact time during SRJ, we hypothesized that individuals with greater hip abduction torque would exhibit higher RJ-indices.

## Materials & methods

### *Participants*

Eleven female university students participated in this study (height: 157.9 ± 3.8 cm, body mass: 56.1 ± 5.8 kg, age: 21.3 ± 1.2 years). Written informed consent was obtained from all participants after the study protocol, including its purpose, methods, and potential risks, was explained both orally and in writing. This study was approved by the Ethics Committee of the Faculty of * University (approval number: 2021-11).

### *Data collection and processing*

### *Jumping performance assessment*

Jump performance was assessed in a biomechanics laboratory at * University. Participants performed SCMJ and SRJ trials using their right leg on a force platform (50 cm × 50 cm, Sports Sensing Co., Ltd.), which recorded ground reaction forces at a sampling frequency of 1000 Hz. For the SCMJ, participants were instructed to "jump as high as possible," whereas for the SRJ, they were instructed to "minimize ground contact time while achieving the highest possible jump."

Ground reaction force (GRF) data were used to identify the frames corresponding to ground contact ($\geq$15 N) and takeoff (<15 N), from which contact time and flight time ($T$) were calculated. Jump height was estimated using Equation (1):

$$\text{Jump height (m)} = 1/8 * g * T \qquad (1)$$

where $g$ represents gravitational acceleration (9.81 $m/s^2$) and $T$ represents flight time. Additionally, the SRJ-index was calculated using Equation (2):

$$\text{SRJ-index (m/s)} = \text{Jump height / contact time} \qquad (2)$$

### *Muscle strength measurement of the extensors of the trunk and lower extremities*

Muscle strength was assessed using an isokinetic dynamometer (Cybex NORM, CSMi), a widely used device for muscle function analysis. Measurements were obtained for five specific joint movements: trunk flexion-extension, hip flexion-extension, hip adduction-abduction, knee flexion-extension, and ankle plantar-dorsiflexion. All measurements were performed on the right leg, with participants executing concentric contractions at an angular velocity of 60°/s. Each trial consisted of one familiarization repetition followed by three full repetitions.

Concentric peak torque values for extension, flexion, adduction, abduction, and plantar and dorsal flexion were measured. These values were normalized by dividing by body mass (i.e., peak torque per body mass). Only extension, abduction, and plantar flexion torques were considered in this study.

Total lower limb extension torque was defined as the sum of peak hip extension torque, knee extension torque, and ankle plantar flexion torque. The percentage contribution of each joint to total lower limb extension torque was also calculated. The measurement procedures for each joint torque assessment using the isokinetic dynamometer are described in detail below (Fig. 1).

(1) Trunk Flexion-Extension Strength

Participants were positioned in a standing posture with the knees flexed at 15°. The rotational axis of the trunk (fifth lumbar vertebra) was aligned with the dynamometer's axis of rotation. The upright posture was defined as 0°, with the range of motion set from 10° extension to 90° flexion.

(2) Hip Flexion-Extension Strength

Participants were placed in a supine position on the measurement seat, with the hip joint center aligned with the dynamometer's axis of rotation. The pelvis was secured with a stabilization belt, and the thigh was secured with a support pad. The posture in which the line segment from the hip joint center to the knee joint center pointed vertically upward was defined as 90°. The range of motion was set from 80° extension to 20° flexion (with the maximum extension position defined as 0° and the flexion range extending from 10° to 110°).

(3) Hip Adduction-Abduction Strength

Participants were positioned laterally on the measurement seat, ensuring that the right hip joint center was aligned with the dynamometer's axis of rotation. The lumbar region and left thigh were stabilized using fixation belts, while the right thigh was secured with a support pad. The neutral position (0°) was defined as the posture in which the segment from the hip joint center to the ankle joint center was horizontal. The range of motion was set from 0° (neutral) to 45° in the abduction direction.

(4) Knee Flexion-Extension Strength

Participants were seated, with the upper body and right thigh secured using fixation belts, and the right lower leg stabilized with a support pad. The maximum extension position was defined as 0°, with the range of motion set from 0° extension to 100° flexion.

(5) Ankle Plantar-Dorsiflexion Strength

Participants were positioned supine on the measurement seat, with the ankle joint center aligned with the dynamometer's axis of rotation. The pelvis was stabilized with a fixation belt, the thigh with a support pad, and the foot with a specialized attachment. The position in which the toes pointed vertically upward was defined as 0°. The range of motion was set from 0° to 50° in the plantar flexion direction and from 0° to 20° in the dorsiflexion direction.

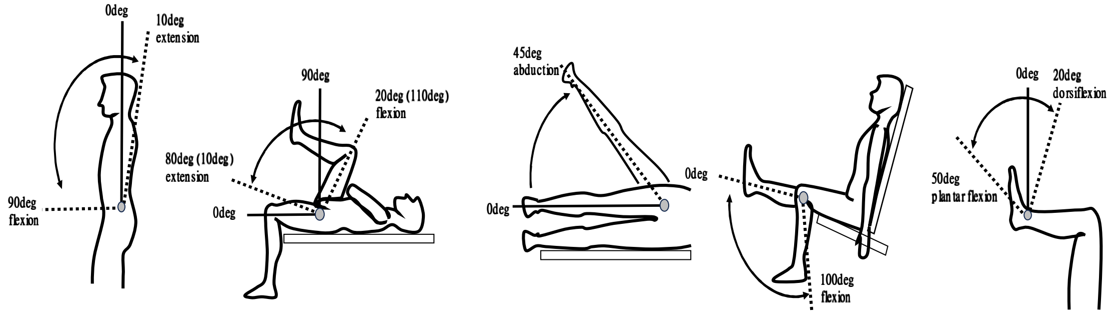

**Fig. 1 Strength measurement using the isokinetic dynamometer.**

*Statistical analysis*

Pearson's product-moment correlation coefficient was used to examine the relationships between the measured variables. In this study, we also calculated the p-value, but due to the small sample size, a correlation coefficient of 0.4 or higher was considered indicative of a moderate relationship. Statistical analyses were performed using Excel 2019 (ver. 2312, Microsoft).

## Results

*Participant characteristics*

Table 1 presents the mean and standard deviation of height and body mass for the 11 participants. The mean height was 157.9 ± 3.8 cm, and the mean body mass was 56.1 ± 5.8 kg.

**Table 1 Participant characteristics (height and body mass).**

| Subj. | Age (years) | Height (cm) | Body mass (kg) |
|---|---|---|---|
| **1** | 22 | 160 | 52 |
| **2** | 23 | 156 | 55 |
| **3** | 22 | 159 | 52 |
| **4** | 22 | 159 | 52 |
| **5** | 22 | 159 | 65 |
| **6** | 22 | 164 | 58 |
| **7** | 22 | 160 | 50 |
| **8** | 20 | 157 | 58 |
| **9** | 20 | 153 | 68 |
| **10** | 19 | 160 | 54 |
| **11** | 20 | 150 | 53 |
| **Mean±S.D.** | 21.2±1.2 | 157.9±3.8 | 56.1±5.8 |

*Jump performance*

Table 2 summarizes the mean and standard deviation of the jump indices. For the SCMJ, the flight time was 0.342 ± 0.023 s, and the jump height was 14.4 ± 1.9 cm. For the SRJ, the contact time was 0.324 ± 0.061 s, the flight time was 0.318 ± 0.039 s, the jump height was 12.6 ± 3.3 cm, and the SRJ-index was 0.406 ± 0.145 m/s.

**Table 2 Jump performance indices.**

| | SCMJ | | SRJ | | | |
|---|---|---|---|---|---|---|
| Subj. | **Flight time (sec)** | **Jump height (cm)** | **Contact time (sec)** | **Flight time (sec)** | **Jump height (cm)** | **SRJ-index (m/s)** |
| **1** | 0.364 | 16.2 | 0.430 | 0.332 | 13.5 | 0.314 |
| **2** | 0.355 | 15.4 | 0.327 | 0.302 | 11.2 | 0.342 |
| **3** | 0.315 | 12.2 | 0.298 | 0.303 | 11.3 | 0.378 |
| **4** | 0.328 | 13.2 | 0.320 | 0.309 | 11.7 | 0.366 |
| **5** | 0.305 | 11.4 | 0.389 | 0.283 | 9.8 | 0.252 |
| **6** | 0.326 | 13.0 | 0.248 | 0.308 | 11.6 | 0.469 |
| **7** | 0.373 | 17.1 | 0.293 | 0.414 | 21.0 | 0.717 |
| **8** | 0.365 | 16.3 | 0.292 | 0.330 | 13.3 | 0.457 |
| **9** | 0.358 | 15.7 | 0.292 | 0.289 | 10.2 | 0.351 |
| **10** | 0.352 | 15.2 | 0.257 | 0.353 | 15.3 | 0.594 |
| **11** | 0.322 | 12.7 | 0.413 | 0.279 | 9.5 | 0.231 |
| **Mean±S.D.** | 0.342±0.023 | 14.4±1.9 | 0.324±0.061 | 0.318±0.039 | 12.6±3.3 | 0.406±0.145 |

*Isokinetic muscle strength*

Table 3 presents the peak torque values for trunk extension and the three lower limb joints. The results indicated that the peak trunk extension torque was 111.8 ± 39.5 Nm (2.1 ± 0.8 Nm/kg), hip abduction torque was 34.4 ± 15.2 Nm (0.7 ± 0.3 Nm/kg), hip extension torque was 92.6 ± 48.5 Nm (1.8 ± 0.9 Nm/kg), knee extension torque was 88.2 ± 24.4 Nm (1.6 ± 0.4 Nm/kg), and ankle plantar flexion torque was 29.6 ± 16.2 Nm (0.6 ± 0.3 Nm/kg). Additionally, the total lower limb extension torque was 210.3 ± 76.9 Nm (4.0 ± 1.4 Nm/kg).

**Table 3 Peak torques of the trunk and lower limb joints.**

| Subj. | Unit | Trunk extension | Hip abduction | Hip extension | Knee extension | Ankle plantar flexion | Lower limb |
|---|---|---|---|---|---|---|---|
| **1** | Nm | 77.8 | 45.5 | 101.2 | 93.1 | 46.7 | 241.0 |
| | Nm/kg | 1.5 | 0.9 | 1.9 | 1.8 | 0.9 | 4.6 |
| **2** | Nm | 148.0 | 36.8 | 42.7 | 82.6 | 28.9 | 154.2 |
| | Nm/kg | 2.8 | 0.7 | 0.8 | 1.6 | 0.6 | 3.0 |
| **3** | Nm | 105.5 | 9.3 | 49.5 | 63.4 | 11.2 | 124.1 |
| | Nm/kg | 2.0 | 0.2 | 1.0 | 1.2 | 0.2 | 2.4 |
| **4** | Nm | 53.7 | 11.9 | 43.9 | 38.8 | 7.1 | 89.8 |
| | Nm/kg | 1.0 | 0.2 | 0.8 | 0.7 | 0.1 | 1.7 |
| **5** | Nm | 12.9 | 34.4 | 49.7 | 99.7 | 9.3 | 158.7 |
| | Nm/kg | 2.5 | 0.7 | 1.0 | 1.9 | 0.2 | 3.1 |
| **6** | Nm | 54.3 | 19.1 | 40.9 | 82.0 | 30.2 | 153.2 |
| | Nm/kg | 1.0 | 0.4 | 0.8 | 1.6 | 0.6 | 2.9 |
| **7** | Nm | 130.3 | 32.3 | 112.4 | 78.3 | 37.8 | 228.5 |
| | Nm/kg | 2.5 | 0.6 | 2.2 | 1.5 | 0.7 | 4.4 |
| **8** | Nm | 163.7 | 37.6 | 158.5 | 118.3 | 30.9 | 307.7 |
| | Nm/kg | 3.1 | 0.7 | 3.0 | 2.3 | 0.6 | 5.9 |
| **9** | Nm | 165.0 | 51.6 | 124.5 | 123.0 | 27.2 | 274.6 |
| | Nm/kg | 3.2 | 1.0 | 2.4 | 1.5 | 0.5 | 4.4 |
| **10** | Nm | 104.7 | 47.2 | 162.6 | 82.5 | 35.0 | 280.1 |
| | Nm/kg | 2.0 | 0.9 | 3.1 | 1.6 | 0.7 | 5.4 |
| **11** | Nm | 97.8 | 52.6 | 132.2 | 108.5 | 60.7 | 301.4 |
| | Nm/kg | 1.9 | 1.0 | 2.5 | 2.1 | 1.2 | 5.8 |
| **Mean±S.D.** | Nm | 111.8±39.5 | 34.4±15.2 | 92.6±48.5 | 88.2±24.4 | 29.6±16.2 | 210.3±76.9 |
| | Nm/kg | 2.1±0.8 | 0.7±0.3 | 1.8±0.9 | 1.6±0.4 | 0.6±0.3 | 4.0±1.4 |

Table 4 summarizes the proportional contribution of each joint's peak torque to total lower limb extension torque. The results showed that hip extension torque contributed 43.1 ± 10.8%, knee extension torque contributed 43.1 ± 10.6%, and ankle plantar flexion torque contributed 13.8 ± 5.3%.

**Table 4 Proportional contributions of peak torque to total lower limb extension torque.**

| Subj. | Hip extension (%) | Knee extension (%) | Ankle plantar flexion (%) |
|---|---|---|---|
| **1** | 42.0 | 38.6 | 19.4 |
| **2** | 27.7 | 53.6 | 18.7 |
| **3** | 39.8 | 51.1 | 9.0 |
| **4** | 48.9 | 43.2 | 7.9 |
| **5** | 31.3 | 62.8 | 5.9 |
| **6** | 26.7 | 53.5 | 19.7 |
| **7** | 49.2 | 34.2 | 16.6 |
| **8** | 51.5 | 38.4 | 10.1 |
| **9** | 54.7 | 33.4 | 11.9 |
| **10** | 58.1 | 29.5 | 12.5 |
| **11** | 43.9 | 36.0 | 20.2 |
| **Mean±S.D** | 43.1±10.8 | 43.1±10.6 | 13.8±5.3 |

*Correlation analysis*

Table 5 presents the correlation coefficients between jump indices and the peak torque of each muscle group. The results indicated that SCMJ jump height (flight time) exhibited moderate to strong positive correlations with trunk extension torque (r = 0.42, p = 0.20), hip abduction torque (r = 0.44, p = 0.18), hip extension torque (r = 0.56, p = 0.07), ankle plantar flexion torque (r = 0.42, p = 0.20), and total lower limb extension torque (r = 0.50, p = 0.11). Additionally, moderate to strong correlations were observed between SCMJ jump height and the proportion of hip extension torque (r = 0.48, p = 0.14) and knee extension torque (r = -0.65, p = 0.03) relative to total lower limb extension torque.

Conversely, no significant correlations were found between SRJ performance and peak torque values of any muscle group. However, moderate correlations were observed between SRJ jump height (flight time) and the proportion of hip extension torque (r = 0.40, p = 0.23) and knee extension torque (r = -0.48, p = 0.14) relative to total lower limb extension torque. Additionally, the SRJ-index exhibited a moderate negative correlation with the proportion of knee extension torque (r = -0.43, p = 0.19).

**Table 5 Correlation coefficients between jump indices and isotonic strength of the trunk and lower limb extensors.**

| | | Peak torque (Nm/kg) | | | | | | Percentage of each joint (%) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Trunk extension | Hip abduction | Hip extension | Knee extension | Ankle plantar flexion | Lower limb | Hip | Knee | Ankle |
| SCMJ | Flight time (sec)<br>Jump height (cm) | **0.42** | **0.44** | **0.56** | 0.16 | **0.42** | **0.50** | **0.48** | **-0.65** | 0.33 |
| SRJ | Contact time (sec) | -0.10 | 0.35 | -0.06 | 0.34 | 0.32 | 0.13 | -0.21 | 0.13 | 0.17 |
| | Flight time (sec)<br>Jump height (cm) | 0.06 | -0.01 | 0.35 | -0.07 | 0.21 | 0.26 | **0.40** | **-0.48** | 0.16 |
| | SRJ-index (m/s) | 0.05 | -0.01 | -0.26 | 0.16 | 0.07 | 0.18 | 0.39 | **-0.43** | 0.07 |

## Discussion

*Relationships between single-leg countermovement jump and isotonic strength of the trunk and lower limb*

Regardless of whether a countermovement jump (CMJ) is performed bilaterally or unilaterally, it is considered equivalent to the vertical mechanical work performed against body mass and is widely used as an assessment index for evaluating lower limb extensor torque in physical fitness testing (Endo, 2007). Based on this premise, the present study hypothesized that athletes with superior SCMJ jump height would also exhibit superior concentric lower limb extensor torque.

The findings of this study revealed that individuals with greater lower limb extensor torque, particularly hip extension torque, achieved higher SCMJ jump heights (Table 5). These results align with a previous study by Shimizu et al. (2024), which examined the relationship between drop jump (DJ) indices and isotonic strength of the trunk and lower limbs in 26 female participants using a Cybex dynamometer. According to Shimizu et al. (2024), hip extension torque accounted for the largest proportion of total lower limb extensor torque, leading to the recommendation of a hip-dominant jumping strategy. Similarly, in the SCMJ trials of the present study, hip extension torque, generated by the large hip muscle groups, was identified as a key factor in achieving greater jump height.

*Relationships between single-leg rebound jump and isotonic strength of the trunk and lower limb*

Achieving a high SRJ-index, whether in bilateral or single-leg jumps, requires maximizing jump height while minimizing ground contact time. Kariyama et al. (2012) conducted an SRJ trial in which 12 male track and field athletes performed 10 consecutive jumps with alternating single-leg takeoffs. Their results showed that, compared to bilateral takeoffs, single-leg takeoffs exhibited greater positive and negative work around the hip adduction-abduction axis, suggesting that hip abduction torque plays an important role in jump height acquisition and postural control. Based on these findings, the present study hypothesized that individuals with superior concentric hip abduction torque would also demonstrate higher SRJ-indices.

However, the results of this study did not reveal significant correlations between the SRJ-index and peak torque in any muscle group, failing to support the hypothesis that hip abductor strength contributes to SRJ jump height or the SRJ-index. Several factors may explain these findings: (1) differences in participant characteristics and athletic ability between male track and field athletes and general female university students,

(2) differences in the jump task—alternating single-leg jumps versus repeated jumps on the same single leg, and (3) the high level of difficulty in executing repeated single-leg jumps within a confined 50 cm × 50 cm area. Notably, in this study, the SRJ trials resulted in an average jump height of 12.6 ± 3.3 cm and a contact time of 0.324 ± 0.061 s, values considerably lower than those reported in previous studies on bilateral jump trials. Some studies suggest that hip abductor muscles contribute more to postural control than directly to jump height (Koike et al., 2006). Therefore, in jump tasks with relatively long contact times and lower jump heights—such as the SRJ trials in this study—the contribution of the hip abductors may be diminished.

On the other hand, a moderate correlation was observed between SRJ jump height and the proportion of total lower limb extensor torque contributed by hip extension torque. This suggests that, for jump tasks involving repeated single-leg takeoffs, hip extension torque may have a more significant positive impact on SRJ performance than hip abductor torque. Previous studies, such as those by Zushi (1995) and Yoon et al. (2007), have reported that in bilateral rebound jump (RJ) or drop jump (DJ) trials, the eccentric contraction of the ankle plantar flexors influences the ability to shorten ground contact time, leading to recommendations for plantar flexor-dominant jump techniques. However, in single-leg jumps with longer ground contact times—such as the SRJ trials in this study—a hip-extensor-dominant strategy may be more beneficial than an ankle- or knee-dominant approach for these tasks.

## Conclusions

This study aimed to clarify the characteristics of the single-leg countermovement jump (SCMJ) and single-leg rebound jump (SRJ) and to examine their relationship with isotonic strength parameters of the trunk and lower limbs. The key findings are summarized as follows:

1) Measurements of peak isokinetic torque in the lower limbs revealed that hip abduction torque was lower than both hip extension torque and knee extension torque but greater than ankle plantar flexion torque.
2) SCMJ jump height exhibited moderate to strong positive correlations with trunk extension torque, hip abduction torque, hip extension torque, ankle plantar flexion torque, and total lower limb extension torque.
3) Moderate to strong correlations were observed between SCMJ jump height and the proportional contribution of hip extension torque and knee extension torque relative to total lower limb extension torque.
4) No significant correlations were found between SRJ performance and the absolute peak torque of any muscle group. However, a moderate correlation was observed between SRJ jump height and the proportion of hip extension torque relative to total lower limb extension torque.

These findings suggest that strength training programs focused on increasing muscle hypertrophy and force output of the hip extensors—particularly the gluteus maximus and hamstrings—may contribute to enhanced single-leg jump performance. Additionally, technical training that emphasizes efficient takeoff mechanics through conscious activation of the hip extensors during jumping movements may further improve performance.

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